# Ideas in Practice: Graphing Calculators in Beginning Algebra

**By Aimee Martin**

ABSTRACT: ***This paper reports on a project to improve Beginning Algebra students' understanding of basic algebraic concepts through fully integrated use of the TI-83 graphing calculator. The methodology incorporated an intervention case study including approximately 700 Beginning Algebra students at an open-door community college of 8,500 students in the Southwest. Pass rates, empirically calculated at points before and after the implementation of the graphing calculator project, clearly showed an increase with the use of graphing calculators.***

*"Placing graphics calculators in the hands of students gives them the power and freedom to explore mathematical territory that may be unfamiliar to the teacher."*

Close to 50% of students entering community colleges need developmental education (Foshay & Perez, 2000); mathematics can be particularly challenging, both to institutions and students. According to Hall and Ponton (2005), mathematics is the subject having the strongest tie to student success in degree attainment. Affective factors, such as negative attitudes and low motivation regarding mathematics, further inhibit student success (Ferren & McCafferty, 1992). Therefore, improving student attitudes regarding mathematics is an issue of major importance in increasing pass rates in any developmental mathematics class (Miller, 2000).

The American Mathematical Association of Two-Year Colleges (AMATYC) has proposed a series of sweeping reforms intended to update both the content and pedagogy of all college mathematics courses before calculus in *Crossroads in Mathematics: Standards for Introductory College Mathematics Before Calculus* (1995) and *Beyond Crossroads: Implementing Mathematics Standards in the First Two Years of College* (2006). Based on a thorough examination of the pre-1995 research on the teaching and learning of mathematics, *Crossroads* made compelling arguments for several changes in the teaching of collegiate mathematics, one of which proposed increasing the intelligent use of technology, including graphing calculators, to improve student comprehension and problem-solving abilities in all developmental and early transfer-level mathematics courses.

Research on the use of graphing calculators in mathematics classes is mixed: Many articles give wonderful advice on how to use the graphing calculator to teach a specific concept, but significantly fewer articles report studies which compare the success rates of the traditional approach to teaching algebra versus the graphing-calculator-based approach to teaching algebra.

Articles by authors such as Darken (1995) and Akst (1995) reveal that leading figures in mathematics education have enthusiastically embraced the teaching of all levels of mathematics by using the graphing calculator. In fact, Bert Waits goes so far as to assert, "to deny college students at any level the power of computer-generated numerical and graphical visualization today is academic misconduct" (Akst, 1995, p. 19). Moreover, "several recent research reports addressing this issue of the relationship between graphics calculator use by secondary or early college students and their understanding of functions...are nearly unanimous in their claim that benefits can be derived from appropriate graphics calculator use" (Wilson & Krapfl, 1994, p. 256). The authors went on to cite several studies supporting the use of graphing calculators to improve students' confidence and overall attitudes regarding mathematics. Unavailable at that time, however, was the observation from Goos, Galbraith, Renshaw, and Geiger (2000) that the active inquiry, calculator-based classroom must be implemented with great care.

> Placing graphics calculators in the hands of students gives them the power and freedom to explore mathematical territory that may be unfamiliar to the teacher; and for many teachers, this challenge to their mathematical expertise and authority is something to be avoided rather than embraced. (p. 318)

AMATYC's 1995 *Crossroads* publication set forth three sets of curriculum and pedagogy standards for the teaching of introductory college-level mathematics: (a) Standards for Intellectual Development, (b) Standards for Content, and (c) Standards for Pedagogy. The Standards for Intellectual Development and the Standards for Pedagogy both advocate the use of technology, as well as the use of modeling and multiple approaches, in working with mathematics.

Graphing calculators provide a means of concrete imagery that gives the student new con-

Aimee Martin
Associate Professor of Mathematics
Amarillo College
P O Box 447
Amarillo, TX 79178
martin-al@actx.edu

> trol over her learning environment and over the pace of that learning process. It relieves the need to emphasize symbolic manipulation and computational skills and supports an active exploration process of learning and understanding the concepts behind the mathematics. (Shoaf-Grubbs, 1994, p. 11)

AMATYC expanded its vision of mathematics reform in their 2006 sequel, *Beyond Crossroads: Implementing Mathematics Standards in the First Two Years of College*. The original "Basic Principles" have been "revisited, updated, and expanded to form the philosophical underpinnings of *Beyond Crossroads*" (p. 10), including "Technology":

> Technology should be integral to the teaching and learning of mathematics. Technology continues to change the face of mathematics and affect the relative importance of various concepts and topics of the discipline. Advancements in technology have changed not only *how* faculty teach, but also *what* is taught and *when* it is taught. Using some of the many types of technologies can deepen students' learning of mathematics and prepare them for the workplace. (p. 11)

Foley (2007) asserts that, in the updated AMATYC document, "the balance between new and old teaching methods, called for in 1995, is now tipped in favor of innovation" (p. 15). Foley goes on to point out the reason why the new document favors these more innovative approaches: "Translating among verbal statements, physical models, geometric diagrams, computer simulations, algebraic formulas, numerical tables, and graphical displays is a sophisticated set of mathematical behaviors, which have become mainstream and essential" (p. 15).

Additionally, the *Beyond Crossroads* expanded vision of collegiate mathematics instruction states that faculty should "establish goals for the use of technology in the classroom, establish assessments to measure the activity, and collect and analyze the data to revise and improve the activity" (AMATYC, 2006, p. 56). The "Teaching with Technology" section concludes with the following list of recommendations and actions for implementation:

> Students will be expected to use technology to do the following:
> - enhance their understanding of mathematics
> - discover mathematical concepts and patterns
> - perform mathematical tasks
> - visualize different representations of the same mathematical concept
> - formulate and test conjectures about mathematical concepts and procedural rules
> - communicate mathematical information and ideas.
>
> Implementation recommendation: Faculty will integrate technology appropriately into their teaching to enhance students' understanding of mathematical concepts and skills.
>
> Actions to support this recommendation
>
> Faculty actions:
> - integrate technology into their teaching of mathematics
> - use technology tools for assessment that are aligned with instruction
> - align technology platforms with those familiar to students, required for future courses, and/or necessary in their future careers.
>
> Departmental/institutional actions:
> - provide technology with options for interactivity between students and faculty supporting classroom activities and student learning of mathematics
> - provide technology for students to learn and faculty to teach mathematics courses (AMATYC, 2006, pp. 56-57)

*"A sophisticated set of mathematical behaviors… have become mainstream and essential."*

At many open admissions community colleges, approximately 80% of entering freshmen test as needing at least one developmental math course; the largest percentage of those students place into Beginning Algebra. Also, faculty and administrators are always looking for ways to improve students' ability to succeed in both their developmental math courses and their subsequent transfer-level math courses. With the goal of improving student performance in Beginning Algebra at my institution, a 3-year intervention introduced the use of the TI-83 graphing calculator into all sections of Beginning Algebra based on research regarding integrating technology in mathematics education.

This article presents background information regarding the history of program changes that were made before this project was implemented. The goals and objectives of the project are outlined. The results of the project and data analysis are presented, followed by a brief discussion of the program changes that have occurred since the conclusion of the project.

## Background

### *Pressure from the Legislature*

In response to the disappointment of the state legislature and college administrators regarding the existing pass rates in the developmental math courses (well under 50%), the Developmental Mathematics Coordinator instituted curriculum and pedagogical interventions designed to increase student success. The instructions were to aim for at least a 60% pass rate in the three developmental math courses. It was also made clear that faculty were not to weaken standards in the developmental classes in order to improve these pass rates; the pass rates should improve only because student understanding and performance had improved. Many professional development experiences led faculty to choose the graphing calculator as the primary tool for improving student success. After attending an intensive 5-day graphing calculator workshop, a strategy was devised to begin introducing the graphing calculator in a pedagogical and curriculum change not only for students but also for faculty.

### *Changes in Developmental Mathematics before the Intervention: 1996-1998*

***Structure of developmental math courses.*** For years, developmental math at Amarillo College was composed of three highly structured courses: Basic Mathematics (a prealgebra course covering fractions, decimals, integers, etc.), Beginning Algebra (covering most of the high school Algebra I topics), and Intermediate Algebra (covering most of the high school Algebra II topics). The students met with an instructor for 3 hours a week of lecture. A series of well-written paperback texts that explained the topics in easy-to-read, step-by-step terms had been used for many years in these courses. All testing was untimed to reduce anxiety and took place in a developmental Math Testing Lab outside of class time. The testing in each course at that time included seven chapter exams, three module exams, and a comprehensive final exam. Students in Basic Mathematics and in Beginning Algebra could take every test twice, and they received the higher of the two grades. Students were given a different form of the test if repeating it. Students in Intermediate Algebra could take each test only once.

***Could requiring homework help student success?*** During the author's first 3 years as coordinator the following changes were made leading up to the implementation of the graphing calculator. The developmental math program was enhanced in small ways by improving and stan-

dardizing the tests in all three courses and also modifying the three curricula slightly. The first major change was requiring regular homework assignments in all sections of the three developmental courses. Up to that time, students were given a list of suggested homework problems to work in preparation for the 11 tests required in each course. Few, if any, students were motivated enough to complete homework problems which carried no credit. Beginning in the Fall 1997 semester, the number of tests in all three courses dropped from 11 to 8, and homework problems that would be graded were assigned from each section of material covered.

The results of this change were, for the most part, quite positive. Faculty commented that students now came to class with fewer difficulties in understanding the material and were better prepared to discuss their problems with a particular section of material after working on the related homework problems. The faculty also asserted that students seemed to perform somewhat better on tests. These improvements were reflected in an increase in the pass rates of all three developmental math courses (see Table 1).

### *Why the Graphing Calculator?*

What was surprising from the data collected on the homework intervention was that even with a clear, readable textbook; untimed tests that students could repeat; and, now, regular homework assignments, the 50% pass rate barrier in Beginning Algebra seemingly could not be broken. Student understanding and performance had improved somewhat but not as significantly overall as in the other two courses.

One trend noticed at this time was diversifying these students' performances even further: Some of the Beginning Algebra students were quite proficient with graphing calculators due to experience using them in high school, whereas other students had never even seen a graphing calculator. The students who had used the calculators in high school were often frustrated with the prohibition against using them in both developmental algebra courses. These same students exhibited a much greater sense of ease with technology in general, not only with hand-held calculators but also with computers.

Every effort was made to address this discrepancy in student exposure to hand-held technology by introducing graphing calculators into all of the Intermediate Algebra classes beginning in the Fall 1997 semester, the same semester the required homework was introduced. A brief history will clarify why the results of this change were somewhat disappointing.

In the late 1980s and early 1990s at Amarillo College, the Mathematics Department's policy regarding calculators stated that no calculators of any kind were allowed in Basic Mathematics, and scientific calculators only could be used in the Beginning and Intermediate Algebra classes. At that time, most of the senior Mathematics Department faculty, who were largely unfamiliar with graphing calculators themselves, felt that graphing calculators weakened students' math skills in the lower-level courses. These skeptics believed that a graphing calculator, in the hands of these mathematically inexperienced students, would end up being a cheating tool that would do the work for students who did not really understand why they were doing what they were doing. As program coordinator, I tended to agree.

*"Anyone who has seen trained teachers use calculators knows that they can be used to teach 'thinking.'"*

When the use of the graphing calculator to approach problems numerically and graphically led to new mathematical insights, I became convinced that the proper use of graphing calculators in algebra classes could greatly enhance developmental students' understanding of fundamental algebraic concepts. I agreed with Waits:

> The idea of teaching students obsolete skills to help them think is nonsense, as is the idea that using calculators causes mental atrophy. It smacks of mathematics only for the elite. And anyone who has seen trained teachers use calculators knows that they can be used to teach 'thinking' and not water down mathematics. (Akst, 1995, p. 19)

Taking this new-found enthusiasm and training into elaborate discussions with the Department Chair and the faculty, the Developmental Mathematics Coordinator was able to require graphing calculators in all sections of Intermediate Algebra beginning with the Fall 1997 semester.

At several different conferences (Doo, Thomas, & Levendusky, 1998) the same piece of advice was given by numerous educators who had introduced the graphing calculator into their own mathematics curriculums: Introducing calculators into the lower-level classes first, followed by their introduction into the higher-level classes was a more effective, consistent approach than the trickle-down theory of using them in higher-level classes before the lower-level classes. The Department Chair had just begun requiring the faculty to use graphing calculators in all sections of College Algebra. Even so, the faculty at the time, still wary of this change, was continuing to teach algebra with a largely traditional approach. Despite recommendations from educators already using graphing calculators, the faculty would only agree to the limited use of graphing calculators in the Intermediate Algebra course.

**Table 1**

***Pass Rates for Developmental Mathematics Courses: Homework Required (Before the Graphing Calculator Intervention)***

| Semester | Basic Mathematics "C" or better | Beginning Algebra "C" or better | Intermediate Algebra "C" or better |
|---|---|---|---|
| Fall 1996 (no homework) | 43.0% | 39.6% | 28.7% |
| Fall 1997 (homework) | 60.1% | 47.9% | *52.7% |
| Fall 1998 (homework) | 64.0% | 48.2% | *50.3% |

*Note:* The Fall 1996 pass rate for Intermediate Algebra was unusually poor compared to previous fall semesters. The typical fall pass rate in this course had been about 40%. Also, the asterisk (*)indicates that an additional major change—discussed in the "Why the Graphing Calculator?" section—other than homework was made in the curriculum at that time.

### *Beginning to Use Graphing Calculators*

The transition began by switching textbooks from a very traditional, symbolic-manipulation Intermediate Algebra workbook to a book by the same author that introduced some generalized graphing calculator exercises into what was still a largely traditional, nongraphing approach to algebra. The stated problems in the new book still did not reflect the types of real-world mathematics problems students might encounter outside of class, and no keystrokes were given for a specific calculator model in the new book. The Intermediate Algebra tests were modified somewhat to try to make use of this book's limited introduction to the graphing calculator.

To further facilitate this change, 128 Texas Instruments TI-83 graphing calculators were ordered to be used by the most financially disadvantaged students as loaner calculators during the semester they took Intermediate Algebra.

Finally, in July 1997 the Mathematics Department sponsored a 3-day workshop on teaching in a multiple-approach curriculum with graphing calculators, offered through The Ohio State University Summer Short Course Program. Although this enlightening workshop demonstrated the advantages of using the graphing calculator in developmental algebra courses, the majority of the Mathematics Department's faculty still disagreed with introducing graphing calculators into the developmental curriculum.

***Initial introduction of graphing calculators in Intermediate Algebra.*** Initially, the plan was to make such a change gradually, trying to gain the approval of a majority of the math faculty; the possibility of piloting the use of graphing calculators in a few sections of Intermediate Algebra was discussed with the chair. However, this approach had to be abandoned due to a resistant administrator. Efforts to adopt a textbook that more fully integrated the graphing calculator into its teaching approach also fell to the circumstances of the time, and the department continued using a largely traditional textbook. And because the calculators were introduced during the same semester (Fall 1997) that homework began to be required in Beginning and Intermediate Algebra, it was not possible to definitively answer which change had contributed more to the improved pass rates in Intermediate Algebra. Both the Mathematics Department Chair and the Developmental Mathematics Coordinator knew that introducing two major changes simultaneously did not support good research-based educational practice; however, it became clear that any allowed changes would need to be made immediately to avoid losing the option to make that change altogether.

***Early impact of calculator use.*** Despite all of these obstacles, however, there was still an observable improvement in students' basic understanding of certain algebraic ideas after the TI-83 graphing calculator began to be used in class. I noticed that inevitable "Aha!" look appearing on faces whenever a problem was examined numerically or graphically. The students asked more thoughtful, higher-order questions in class. And because the increase in the Intermediate Algebra pass rates was higher overall than the increase in the Beginning Algebra pass rates from the Fall 1997 through Spring 1999 semesters—when homework was required in both courses—it appeared that the superior pass rates of the Intermediate Algebra students were at least partly due to an improved understanding of algebra from using graphing calculators. It seemed likely that even greater success could be achieved with the developmental students' grasp of algebra if the proper changes were made: adopting a "graphing-calculator-friendly" textbook that presented multiple approaches to solving algebra problems and introducing the graphing calculator into the first Beginning Algebra course.

***Integrating complementary text.*** Around this time a new text came in for evaluation, one unlike any of the books previously examined. The earlier algebra books, all trumpeting their newly integrated graphing-calculator approach, still seemed to be traditional-approach books with a superficial introduction to a few specialized graphing calculator problems. Moreover, no specific directions for actually using a graphing calculator were ever provided; the student was always referred to the calculator manual.

This new text was a single text intended for a 2-semester Beginning/Intermediate Algebra sequence. The book used multiple approaches—numerical, graphical, symbolic, and verbal—to solve algebra problems. It also used the graphing calculator in such an integral way that it gave the specific TI-83 keystrokes needed to work numerous problems in "Technology" boxes throughout the book. For the first time in this college setting, students (and faculty) did not have to constantly refer to often poorly written, frustrating instruction manuals to try to figure out how to work a specific problem. The book also made specific references to the AMATYC (2006) Standards it was designed to implement.

*Mathematics Department faculty still disagreed with introducing graphing calculators.*

This huge, well-written book, *Experiencing Algebra* (Thomasson & Pesut, 1999), contained all of the elements necessary to support a multiple-approach, graphing-calculator-based curriculum. It would be the basis for implementing a graphing-calculator-based curriculum in Beginning Algebra.

## The Graphing Calculator Intervention

### *Importance of this Project*

The American Mathematical Association of Two-Year Colleges' 1995 *Crossroads* document presented standards considered to be the most advanced, research-based ideas for teaching developmental mathematics. The expected benefits of introducing the graphing-calculator-based text to the Beginning Algebra students were based on these principles and were threefold. First, the move to earlier introduction to hand-held technology in the mathematics curriculum was in accord with AMATYC's Standard I-6: "Students will use appropriate technology to enhance their mathematical thinking and understanding and to solve mathematical problems and judge the reasonableness of their results" (p. 11). Second, the new textbook's approach to teaching algebra numerically, graphically, and algebraically supported both Standard P-1, "mathematics faculty will model the use of appropriate technology in the teaching of mathematics so that students can benefit from the opportunities it presents as a medium of instruction" (p. 15), and Standard P-4, "mathematics faculty will model the use of multiple approaches—numerical, graphical, symbolic, and verbal—to help students learn a variety of techniques for solving problems" (p. 16). Third, the textbook's emphasis on modeling real-world problems followed AMATYC's Standard I-2, "students will learn mathematics through modeling real-world situations" (p. 10).

### *Goals and Objectives of the Graphing Calculator Intervention*

**Goals:**

1. To increase student understanding of basic algebraic concepts, which will result in increased student pass rates.

**Objectives:**

1. To increase students' technical expertise in the use of the TI-83 graphing calculator in all sections of Beginning Algebra.
2. To familiarize developmental math students with the use of the TI-83 graphing calculator in Beginning Algebra as a higher order problem-solving tool.

**Strategies:**

1. Introduce the new graphing-calculator-based text to all sections of Beginning Algebra in Fall 1999.
2. Provide training in teaching Beginning Algebra with the TI-83 graphing calculator for all developmental algebra faculty in the form of a day-long workshop.
3. Provide equal student access to the TI-83 graphing calculator; the policy in use for checking out loaner TI-83 calculators to financially disadvantaged students needed to be reviewed and revised.
4. Integrate the calculator-based approach into the Beginning Algebra curriculum by means of:
   (a) developing course-wide in-class activities, tests, and homework assign-

ments using the TI-83 calculator and reflecting the new approach being used in the new graphing-calculator-based text and
   (b) sharing ideas and eliciting feedback on the new approach and materials with full-time and adjunct faculty.
5. Calculate the pass-rate change in Beginning Algebra after a full and successful introduction of the graphing calculator to the students.

## Method

### Population and Site Description

The study was conducted at an open-admission community college serving a sparsely populated area in the Southwest. The Fall 1999 population for this study was strikingly similar to that of the college as a whole. Of these 718 Beginning Algebra students, 40% were male and 60% were female. Ethnicity demographics of this population were also similar to the overall college: white students comprised 72%, African-American students made up 4%, and Hispanic students formed 21% of the Beginning Algebra student group. The majority (72%) of Beginning Algebra students were under age 25, with 27% between the age of 25 and 49, and only 1% age 50 or older. There was a total of 24 sections of Beginning Algebra in Fall 1999, with four of those sections offered as night classes. A combination of at least 10 different faculty, both full time and part time, taught these Beginning Algebra courses. In all the developmental math courses at the school, teachers face students with strikingly diverse backgrounds in a single class.

### Procedure: Preparing for Graphing Calculator Use

1. In early March 1999 each full-time faculty member was given a copy of the graphing calculator-based textbook. After instructor examination, the decision was made to promote adoption of the 2-semester textbook rather than separate 1-semester books; some faculty suggested that a combined book would reduce the amount of overlapping material covered in Beginning Algebra and Intermediate Algebra. This book's substantially different approach was also explained to faculty, and several suggestions from their feedback were enacted including waiting to adopt the book for the Intermediate Algebra course until Spring 2000 using a "rolling adoption" policy.

2. In July of 1999, the Developmental Coordinator set up a 1-day workshop by the text authors to introduce the new textbook and its approach to faculty. A footnote had already been placed in the "Mathematics" section of the Fall 1999 schedule of classes stating that a graphing calculator, preferably the TI-83 or TI-83 Plus, was required for all students enrolled in Beginning Algebra.

3. On August 25, 1999, before classes began, the textbook authors came for a day-long workshop to explain the pedagogy behind the book. They also gave extensive demonstrations and handouts on using this text and the TI-83 calculator together in class. During this workshop the faculty were also familiarized with the accompanying computer tutorial software. On September 1, 1999, the Department Chair and the Developmental Mathematics Coordinator met with the evening adjunct faculty and other faculty unable to attend the August workshop and provided workshop handouts and a brief summary of presented information. All faculty were also given copies of the ancillary instructor's solution manual that contained step-by-step solutions to all of the even-numbered exercises in the book.

4. In August 1999, with feedback from a faculty member experienced in the use of graphing calculators, homework problems that would be assigned from each section of covered material were selected. Such homework assignments were created using the parameters given in Part (a) of Intervention Strategy #4 (AMATYC, 1995). The course syllabus, the lecture/suggested test schedule, and the homework assignment sheet were all updated by the Math Lab staff. These documents were checked for accuracy and for appropriate timing of the material to be covered. During this time the supervisor of our Math Testing Lab was given a copy of the test bank that accompanied the book. He then created draft copies of the three different versions of each of the six chapter tests. Each test would have 12 problems to work, at least one or two of which had to be realistically stated problems. The tests were extensively edited, changes made, test keys created and checked, and the tests sent to our print shop.

The three versions of the midterm exam were created in a similar way but with 20 problems addressing the material from the first three chapters. The final exam was comprehensive, and each version contained 25 problems, four of which were word problems. Several problems on each test were difficult or impossible to work without a graphing calculator. The new tests reflected the sophisticated, multiple approach of the new book, striving to ensure that problems were not any easier overall than on previous tests. Homework assignments were also created using the parameters given in Part (a) of Intervention Strategy #4 (AMATYC, 1995). The creation of the new tests was completed by October 1999.

5. As Developmental Mathematics Coordinator, I chose to teach one section of Beginning Algebra that semester so that I would have first-hand experience with challenges facing faculty during initial project implementation. The Department Chair and Developmental Mathematics Coordinator also worked to give as many different adjunct faculty as possible at least one section of Beginning Algebra to build a diverse faculty sample into the intervention. A few full-time faculty had already agreed to teach a section of the course.

*Students were given instructions on how to apply for a loaner calculator and informed that proof of financial need was required.*

### Adjustments to the Intervention

The procedure for the distribution of loaner graphing calculators was streamlined. The need for faculty signatures was removed by eliminating the form students previously had to fill out to receive a calculator. A clear, detailed statement of the loaner calculator policy was placed in the course syllabus for Beginning Algebra. In that statement students were given instructions on how to apply for a loaner calculator and informed that proof of financial need was required to receive a calculator.

Here, a delicate balance had to be struck between the requirements of a standardized Beginning Algebra curriculum and the different teaching styles of the faculty. On the homework assignments, the goal was to assign as many different types of problems as possible from each section of homework. Thus, whenever the text offered problems that allowed students to work on a concept numerically, graphically, and algebraically, homework problems were selected using all three approaches. Each test reflected the variety of approaches seen in the homework exercises. Moreover, there were at least a few problems to solve on each test that required calculator use.

The equipment provided in each classroom encouraged the hands-on use of the calculator in class. Each room contained a bright-light overhead projector with a TI-83 viewscreen already locked to the projector. Faculty only needed to carry their own calculator to class and hook it up to the viewscreen to be ready to use it. Even with such a conducive environment, however, the in-class use of the calculator varied widely

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from teacher to teacher. Faculty were also encouraged to take full advantage of the book's excellent "Discovery" and group exercises whenever they could work such exercises into their class time.

### *Data Collection*

All faculty teaching Beginning Algebra received periodic memos which alerted them to errors in the text, asked them for feedback, and informed adjunct faculty of the departmental meeting held in November to discuss the book and its new approach. During September and October 1999 informal feedback was gathered from individual faculty members teaching the course. Topics discussed included the strengths and weaknesses of the text, rewards and challenges of using the graphing calculator in class, pedagogical issues, new approaches to solve classic algebra problems, usefulness and relative difficulty of test questions, student reactions to the calculator, and so forth. At the November 1999 Mathematics Department meeting, the new Beginning Algebra curriculum and textbook were analyzed in a group discussion by those full-time and adjunct math faculty in attendance. Improvements for the Spring 2000 semester were suggested and discussed.

For the qualitative findings, primarily anecdotal data were gathered from faculty comments during meetings; a brief faculty questionnaire regarding the changes that had been made; and student comments made in class to the developmental Mathematics Coordinator, other faculty members, and staff in our developmental Math Testing Lab. For the quantitative findings, data were requested from the college's Director of Institutional Research who collected the pass rates for the Fall 1999 through 2000 Beginning Algebra students in a report that he produced every semester as part of the college's institutional research in the Mathematics Department.

## Results

### *Qualitative Findings*

The qualitative findings regarding participants' opinions of the graphing calculator intervention were, not surprisingly, both positive and negative. Some faculty became enthusiastic supporters of the new approach, some faculty approved of some aspects of the new approach, and some faculty still did not accept the new calculator-based approach. Overall, most instructors became more comfortable with the new methods as the semester progressed.

The majority of faculty, and especially the Mathematics Department Chair, felt that the tests and the level of material presented were now more difficult than the material students saw in the previous curriculum. No concern was expressed then that using the new approach had weakened academic standards.

Student responses to the new approach were as varied as the faculty responses. Some students thought the calculators were wonderful tools for solving problems and clarifying concepts. Some students thought they were reasonably useful but the benefits provided by the calculator did not justify its cost. Some students felt that the calculator was a complicated, confusing, expensive machine that only worsened their anxieties about math and technology in general. Informal observation by the Mathematics Department Chair led to the discovery that most of these students seemed to be in those sections of the course taught by faculty who tended to be more critical of the new curriculum.

The extensive use of technology in class by relatively inexperienced faculty took up so much in-class time that we decided to shorten the Beginning Algebra curriculum by three sections during the Fall 1999 semester. The majority of faculty simply could not adequately cover the material in the original curriculum by the end of the semester. This change was continued for the Spring 2000 semester, as well, to see whether the faculty would become sufficiently comfortable with the new approach to cover more material in Fall 2000.

Some faculty expressed concern about introducing the numerical/graphical approach to solving a particular type of problem before they explained the algebraic approach to solving that type of problem. They believed this order of methodology encouraged students to become overly dependent on the calculator at the expense of mastering important algebraic manipulation skills. Some faculty dealt with this problem by introducing the algebraic approach first and emphasizing its importance. They then discussed the numerical and graphical approaches.

I personally preferred the text authors' order of approaches, finding the numerical and graphical methods provided wonderful discovery exercises and stimulated students' inductive reasoning skills and abilities to formulate general mathematical rules. I would also emphasize the importance of working the problem algebraically to ensure the accuracy of answers, to bypass weaknesses in the graphical representation of certain types of relations, and to avoid the inherent limitations of the TI-83 calculator in manipulating variables. Students were further encouraged to view the calculator as a tool to be operated by them as knowledgeable mathematicians.

### *Quantitative Findings*

The quantitative results of the study were quite positive. The Director of Institutional Research noted that for the first time since these pass rate statistics had been studied, the pass rate in Beginning Algebra exceeded the 50% barrier. As well, he advised an examination of not only the "C or better" pass rates but also the "B or better" pass rates and the student withdrawal rates. The comparison for the Fall 1998 and 1999 semesters is reflected in Table 2.

The substantial increase in the "B" or better percentage suggested that students were truly improving in their fundamental understanding of algebraic concepts, not just scraping by with what could have been a barely passing grade of "C." Moreover, the decline in student withdrawals implied that the students were more motivated to complete the course, possibly because they were more interested in the material from using this new technology to work with previously "boring" algebra problems. The subsequent Spring 2000 semester comparisons were even more exciting (see Table 2).

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**Table 2**

***Comparison of Fall 1998/Fall 1999 and Spring 1999/Spring 2000 Beginning Algebra Pass Rates Before and After the Graphing Calculator Intervention***

| Semester | Beginning Algebra Passing ("C" or better) | Beginning Algebra "B" or better | Beginning Algebra Withdrawals |
|---|---|---|---|
| Fall 1998 (without the TI-83) | 48.2% | 32.6% | 26.0% |
| Fall 1999 (with the TI-83) | 53.3% | 41.0% | 19.0% |
| Spring 1999 (without the TI-83) | 40.5% | 27.9% | 32.6% |
| Spring 2000 (with the TI-83) | 52.9% | 38.9% | 22.3% |

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## Discussion

Confidence in both the qualitative and quantitative findings of the study is augmented not only because of the large cohort of Beginning Algebra students in the sample—550 to 700 per semester—but also because of the wide variety of teachers participating in the intervention. Approximately 30 faculty, both full time and part time, some with public school teaching backgrounds, all with their own teaching styles, participated in the intervention.

### *Limitations*

The foundation for this project began with examination of the new text in Spring 1999, homework problems and handouts completed in Summer 1999, and full implementation in Fall 1999; this phased process may have impacted results. Since the entire population of 718 Beginning Algebra students participated in the intervention, students were not randomly assigned to experimental and control groups. Although intervention designers purposefully assigned a broad range of instructors to teach Beginning Algebra, the amount of training, prior experience, and/or attitudes of instructors were not controlled.

### *Evidence-Based Curriculum Changes since the Project*

Any curriculum is always a work in progress. It is difficult to tease out the role of one component of change versus another component of change in improving student success. Because the graphing calculator program was rejected by the department as a whole, however, it is useful to interpret the data after the return to a more traditional curriculum. This project is a case study of an intervention using the graphing calculator in an effort to increase learning as indicated by student pass rates. Underlying this project are evidence-based values that should be guiding the teaching decisions in higher education today.

The new, graphing-calculator-based curriculum was used in the Beginning and Intermediate Algebra courses through the Spring (and Summer) 2002 semesters. Minor modifications in sequence of topics and material covered were made to continue to refine and improve the approach. In Beginning Algebra, the "C or better" pass rates consistently remained above 50% during the duration of the new curriculum, and even hit a high of 58.2% during the Fall 2000 semester. The "B or better" pass rates each semester—from 35.7% in Spring 2001 to 42.6% in Fall 2001—also continued to remain well above the Fall 1998/Spring 1999 "B or better" precalculator percentages.

**Table 3**

***Comparison of Pass Rates from Four Curricula Designs: Fall 1998-Fall 2006***

| Semester | Beginning Algebra "C" or better | Beginning Algebra "B" or better | Beginning Algebra Withdrawals |
|---|---|---|---|
| Fall 1998 (original traditional curriculum only) | 48.2% | 32.6% | 26.0% |
| Fall 1999 (TI-83 calculator-based curriculum) | 53.3% | 41.0% | 19.0% |
| Fall 2001 (TI-83 calculator-based curriculum) | 57.1% | 42.6% | 18.0% |
| Fall 2002 (new traditional curriculum only) | 47.8% | 32.0% | 19.0% |
| Fall 2004 (new traditional curriculum + new tutoring policy/skill drills) | 49.4% | 33.0% | 18.0% |
| Fall 2006 (new traditional curriculum + new tutoring policy/skill drills) | 52.8% | 40.0% | 18.0% |

Despite these notable gains, however, the Mathematics Department faculty voted to return to a traditional, nongraphing-calculator-based curriculum for Beginning and Intermediate Algebra beginning in the Fall 2002 semester. A new series of texts by a different author was chosen that incorporated many application problems in the homework exercises. The Beginning Algebra textbook offered no graphing calculator exercises at all, whereas the Intermediate Algebra textbook offered a few graphing calculator exercises at the end of most of the homework sections. None of these textbook calculator problems was included in the Mathematics Department's Intermediate Algebra homework assignments. Scientific calculators were again the only calculators allowed in Beginning Algebra, and graphing calculator use by the students was listed as "optional" for use on both homework and tests in Intermediate Algebra.

Over the next few semesters (Fall 2002 through Summer 2003), the new Developmental Mathematics Coordinator reduced the number of problems in most of the homework assignments in all three developmental math classes so that the number of problems assigned per section was now a multiple of five. For example, an original assignment of 18 problems was now cut to 15 problems in order to fit this new, seemingly arbitrary structure. Consequently, some of the more challenging, often application, problems that would have caused the assignment to exceed the allowed number of homework problems were eliminated. Also, instructions on the redesigned tests no longer consistently required complete sentence answers to the application problems; this requirement had supported the *Crossroads* (AMATYC, 1995) Standard I-5, "Students will acquire the ability to read, write, listen to, and speak mathematics" (p. 11).

Further changes were then made in Fall 2004 with the Summer 2004 appointment of the new Mathematics Department Chair. The new chair was eager to put substantially more resources and effort into the developmental math program, so she implemented several sweeping changes in all three developmental math courses during the Fall 2004 semester:

(a) the establishment of the Math Outreach Center, a mathematics tutoring center staffed with one full-time and several part-time tutors;
(b) the implementation of short, timed "Skill Drills" (i.e., pop quizzes) at the beginning of each class over the previous homework assignment, and
(c) A new policy requiring any student who scored below a 70 on any test to receive at least 30 minutes of mandatory tutoring—from the student's instructor or the Math Outreach Center—before being allowed to take the subsequent test.

I agreed with the new mandatory tutoring policy because it required students to get some kind of professional help instead of allowing them to go back in to take a test and repeat many of their previous mistakes. The Department Chair stated that her comparison of the Basic Mathematics test scores during the 1st semester of the new policy and the previous semester showed that test scores improved an average of 20 points with mandatory tutoring compared to only 12 points without mandatory tutoring.

The results of the post intervention changes are presented in Table 3. The pass rates from Fall

1998 through Fall 2006 demonstrate patterns of student success under various curriculum. After 4 years of the reintroduced traditional curriculum favored by the majority of the Mathematics Department faculty and after 2 years of the Outreach Center, skill drills, and mandatory tutoring policy implementation, both the "C or better" pass rates and the "B or better" pass rates in Beginning Algebra have remained below both of those pass rates achieved during the 1st semester—Fall 1999—of the graphing calculator project.

The demographics of the student population in Beginning Algebra have remained essentially the same. Student enrollment has remained approximately the same in the course, with a peak enrollment of 904 students in the Fall 2004 semester of Beginning Algebra. The policy for taking tests, turning in homework, skill drills, and mandatory tutoring has also been maintained through the Spring (and Summer) semesters.

## Implications for Practice

What can be learned from this project and the Mathematics Department's subsequent return to a traditional-approach curriculum? Darken (1995) perfectly captures both sides of such an experience when, speaking of these types of changes in algebra courses, she states,

> There are many lessons to be learned from the experiences of calculus reformers: Change means a lot of hard work; consensus is often illusive but not always necessary; we will make mistakes; many of our colleagues will refuse to change, no matter how convincing our arguments; and many students will resent change, because it doesn't fit with their previous mathematical experiences. On the positive side, we will be thrilled by the new meaning we will find in our curriculum, by the excitement of many of our students as they learn to use mathematics

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> intelligently, and by the knowledge that we are moving away from teaching out-of-date material. (p. 26)

Anyone who has tried unsuccessfully to implement a change in practice or policy has asked themselves, “What could I have done differently to have made this attempted change a success?” A few years of hindsight have provided a list of insights, perhaps incomplete, about what to do differently given another opportunity to affect department-wide change in a developmental math course.

1. Before naively attempting any curriculum changes with only the verbal approval of the Department Chair, I would have required a written job description which clearly provided for risk-taking in curriculum development and clearly gave the Developmental Mathematics Coordinator the authority to make necessary changes based on evidence-based curriculum decisions.
2. I would have contracted with the department faculty as a whole to hold them accountable for making curriculum decisions that are evidence based.
3. I would have contracted with the Department Chair and full-time faculty for a written, specified intervention time of 4 academic years to introduce and refine this project.
4. I would have held a meeting with all full-time faculty to discuss more specifically the characteristics of the new textbooks.
5. Despite some of the faculty’s wishes, I would not have used a single textbook designed to cover the material for two different developmental math courses (in this case, a combined Beginning/Intermediate Algebra textbook), believing that students need more than one exposure to master certain basic algebraic skills such as factoring. A combined text discouraged the practice of repeating/reviewing topics and gave less flexibility in arranging topics in the order desired in both courses. It seems evident that using the separate textbooks by these authors for Beginning Algebra and Intermediate Algebra would have helped to avoid most of those challenges.
6. As part of the intervention project, I would have implemented a previous year of preparing the faculty for this change, including: (a) a pre-intervention workshop on the AMATYC (1995) *Crossroads* principles, obtaining a consensus on the departmental measures of success and a list of approximately 10 paper-and-pencil symbolic manipulation skills that students must possess after completion of the developmental algebra courses and (b) additional intradepartmental graphing calculator workshops, again before the intervention, that discussed methods for teaching some of the specific Beginning Algebra topics with the new graphing-calculator-based approach, with special emphasis on how each lesson should reflect some of the *Crossroads* principles.

## Conclusion

Since mathematics is the subject in which most students are underprepared upon entry to post-secondary education (McCabe, 2003), educators should embrace changes that result in greater student success even if they are personally challenged by the new system. In *Beyond Crossroads: Implementing Mathematics Standards in the First Two Years of College* (2006), the follow-up document to their visionary *Crossroads (1995)* document, AMATYC has expanded rather than retracted any of their original proposals for reform of the early college mathematics curriculum. Their latest proposals for improving the teaching of collegiate mathematics provide a more

*Educators should embrace changes that result in greater student success.*

holistic, college-wide approach that includes such areas as the assessment and placement of students, the creation of optimal learning environments for all students, and the appropriate use of all forms of technology—not just graphing calculators—in the mathematics classroom. The document also provides specific lists of “actions” for students, faculty, and departments/institutions to guide them in implementing the reforms discussed.

With the graphing calculator intervention at our institution ending 6 years ago, the traditional-approach curriculum continues. Basic algebraic skills are being taught in a lecture-based format with drill-and-practice homework assignments. Supported now by a costly math tutoring lab at Amarillo College, pass rates in Beginning Algebra are below the pass rates achieved in the Fall 2001 semester using the graphing-calculator-based curriculum without the support of the Math Tutoring Lab (see Table 4). This intervention takes its place in the production of growing evidence supporting the *Crossroads* (AMATYC, 1995) arguments for the inclusion of graphing calculators in developmental mathematics. Lessons learned regarding the implementation of new curriculum and pedagogy in the community college environment may assist innovative educators to actualize change just as much as data supporting improved student performance.

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~~*David C. Caverly (DCaverly@TxState.edu) is a professor of curriculum and instruction and Director of the Developmental Reading Program at Texas State University-San Marcos, San Marcos, TX 78666.*~~



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